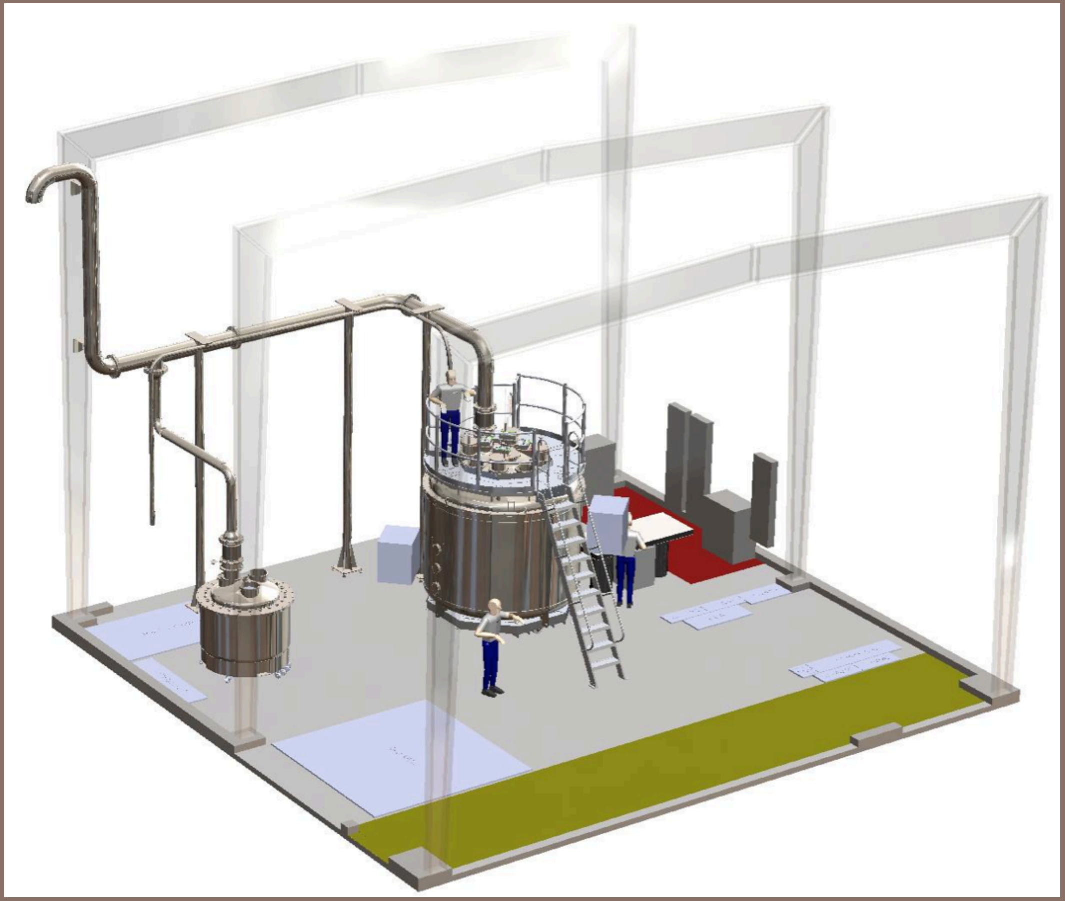

CAPTAIN

CRYOGENIC APPARATUS FOR PRECISION TESTS OF ARGON INTERACTIONS WITH NEUTRINOS

arXiv: 1309.1740

TAUP 2013
Asilomar, CA
September 8-13

Qiuguang Liu
qgliu@lanl.gov

Los Alamos NATIONAL LABORATORY EST. 1943

The CAPTAIN Experiment

- Began as a LANL LDRD project to make measurements of scientific importance to Long-Baseline Neutrino Experiment
- Evolved into a multi-institutional collaboration

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University of Alabama
Z. Djurcic
Argonne National Laboratory
V. Gehman, R. Kadel, C. Tull
Lawrence Berkeley Laboratory
H. Chen, V. Radeka, C. Thorn
Brookhaven National Laboratory
H. Berns, C. Grant, E. Pantic, R. Svoboda, M. Szydagis
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University of California, Irvine
D. Cline, K. Lee, H. Wang, A. Teymourian
University of California, Los Angeles
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Fermi National Accelerator Laboratory
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J. Danielson, S. Elliott, G. Garvey, E. Guardincerri, D. Lee, Q. Liu, W. Louis, C. Mauger, J. Medina, G. Mills, J. Mirabal, J. Ramsey, K. Rielage, C. Sinnis, W. Sondheim, C. Taylor, R. Van de Water, A. Yarritu
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State University of New York at Stony Brook
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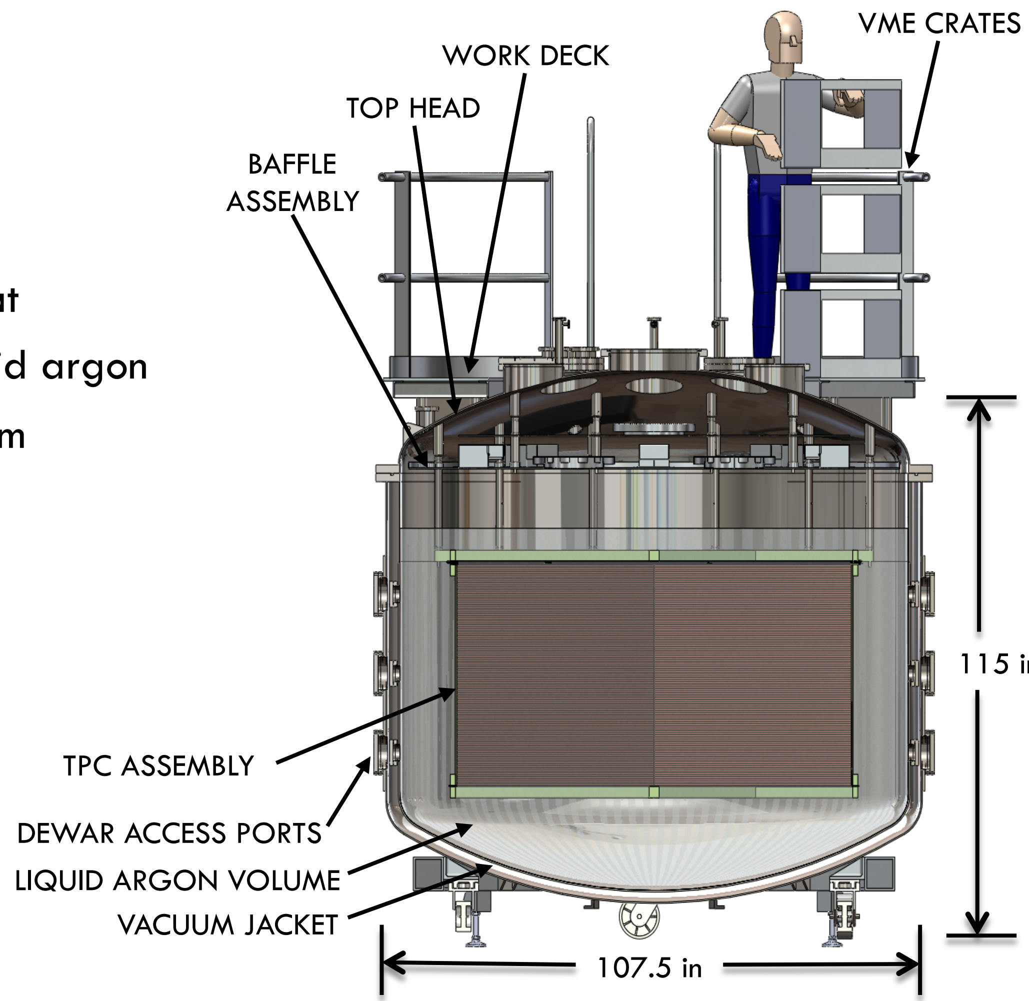
University of South Dakota
R. McTaggart
South Dakota State University

The CAPTAIN Detector

- Liquid argon TPC detector
  - Portable and evacuable cryostat
  - 7700 L, 5-ton instrumented liquid argon
  - Transportable purification system
- Hexagonal shape TPC
- Nd-YAG laser system
- Photon detection

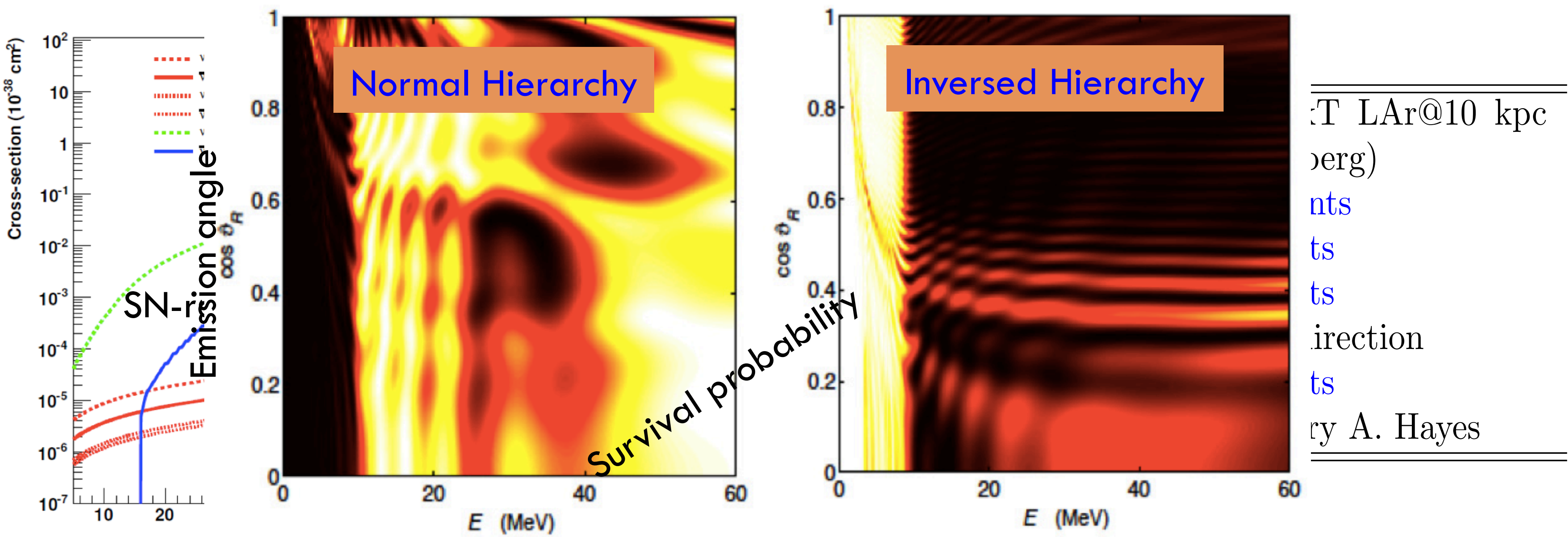


Rich physics programs to address LBNE challenges

- Low energy neutrino run (supernova neutrino, <50 MeV)
- Medium energy neutrino run (neutrino oscillation, 1-10 GeV)
- Neutron run – understand physics feasibility and study backgrounds
- The list is not exclusive

Supernova Neutrino (<50 MeV)

- Supernova neutrino studies are great interests to both particle physics and astrophysics
- LBNE: 34 kton LarTPC would detect more than 3000 events from SN at 10kpc
- It also enables mass hierarchy determination



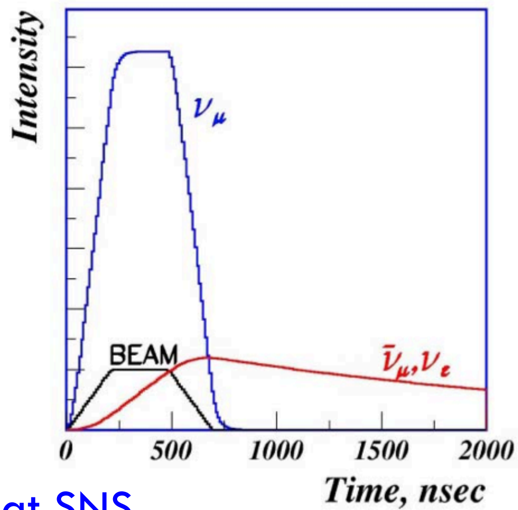
H. Duan, G. M. Fuller, and Y. Quan Ann. Rev. Nucl. Part. Sci. 60 (2010) 569

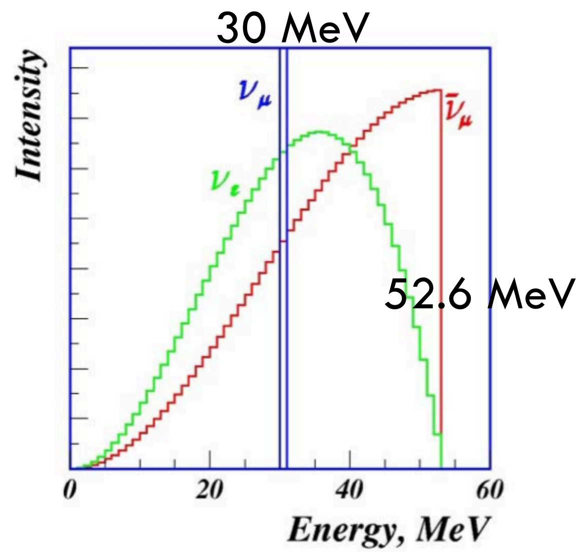
Supernova Neutrino (<50 MeV)

- CAPTAIN:
  - Unique opportunity to measure ν -argon cross sections in CC and NC channels
  - Flavor tagging and background reduction
  - Background studies (neutron run): cosmic ray muon induced spallation processes
- The desire for such an experiment has been around for a decade, now we have a detector available.

K. Scholberg PRD 73, 033005 (2006)
Y. Efremenko and W. Hix arxiv: 0807.2801

Stopped pion sources



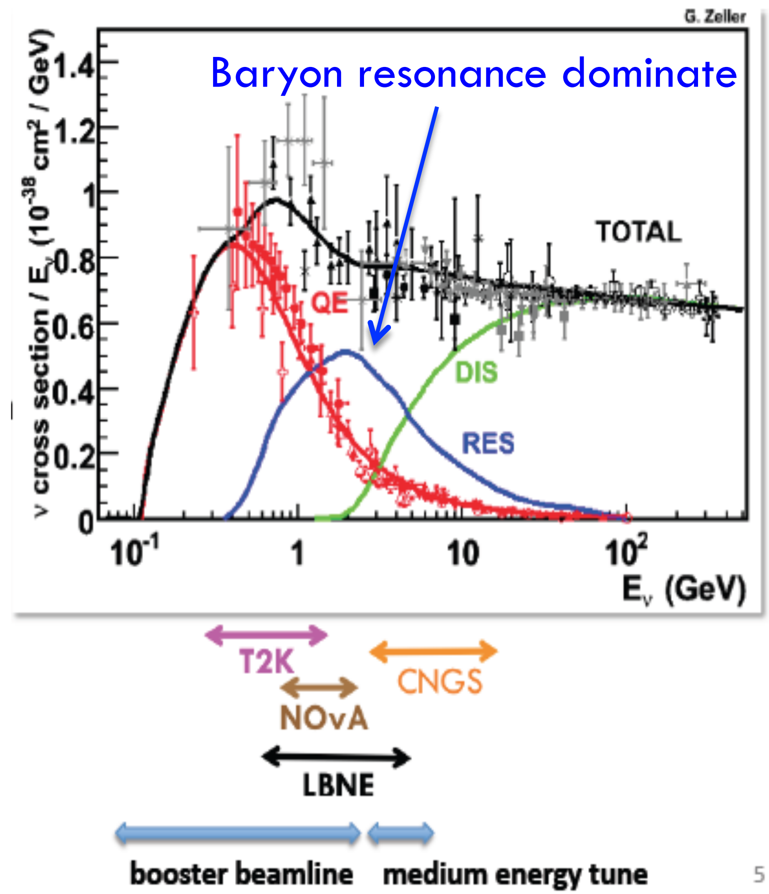


Pulsed beam at SNS

- The Spallation Neutron Source (SNS) at ORNL
  - Along with its intense neutron beam (~1MWatt), SNS provides the world's most intense pulsed source of neutrinos.
  - Stopped pion inside the mercury target decay and produce neutrino with a flux of $\sim 2\times10^7\ \nu/\mathrm{cm}^2/\mathrm{s}$ at 20 m from the spallation target.

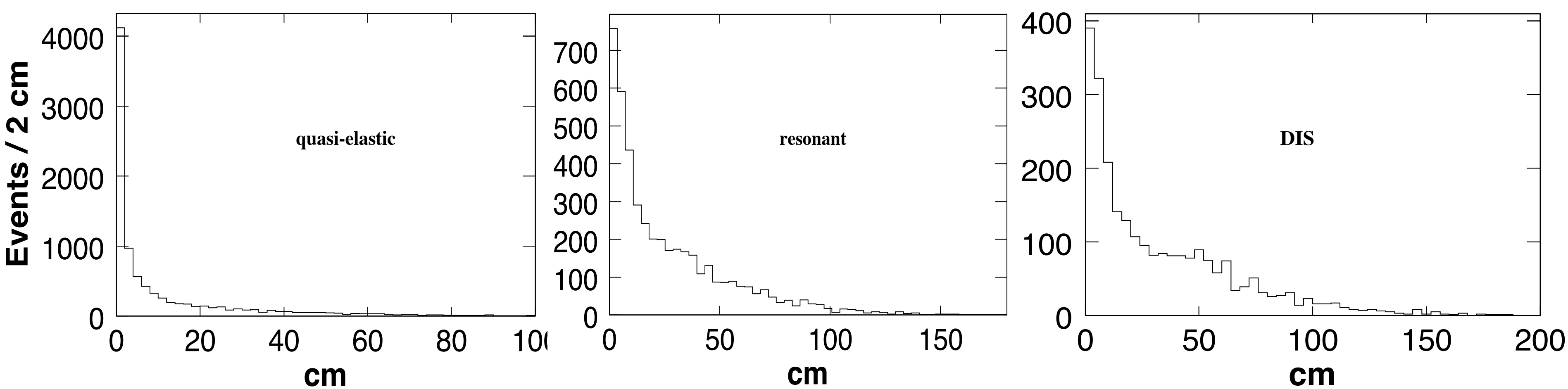
Medium Energy Neutrino Run (1-10 GeV)

- Run on on-axis in NuMI at Fermilab
- Energy region in complimentary to MicroBooNE (Booster)
- Measure exclusive and inclusive cross sectons:
  - Cover the threshold region for pion production
  - Cover the resonance region
- Reconstruction experience with higher energy neutrino interactions
- Same beam and same detection technique to LBNE



Medium Energy Neutrino Run

- Plots show the distance from the vertex to the endpoint of the longest track for contained events
- Contained event: particles, except muon/neutron, are contained in the detector
- 10% containment with the chosen size for CAPTAIN
- 10^6 neutrino interaction per 10^{20} POT; anticipate 4 x10^{20} POT/year
- Expect 370,000 contained CC events/year during a NuMI medium energy run



K. Yarritu (LANL)

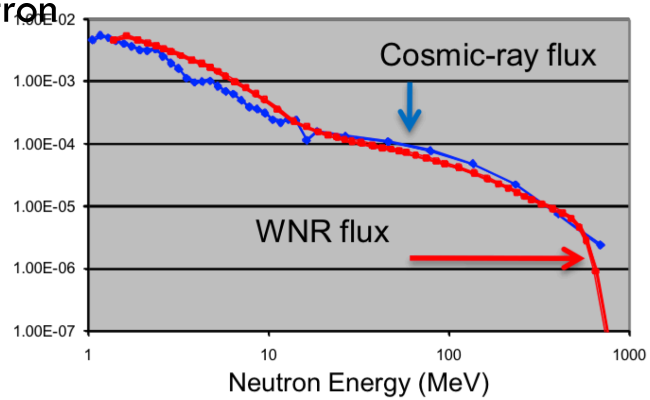
Neutron Run

- Take neutron data at Los Alamos Neutron Science Center (LANSCE) WNR
- Neutron spallation of the argon nucleus
  - A major background to supernova neutrino studies
  - Similar final state feature test the ability to detect supernova neutrino neutral-current interaction

$$\nu_x + {}^{40}Ar \rightarrow \nu_x + {}^{40}Ar^*(NC)$$

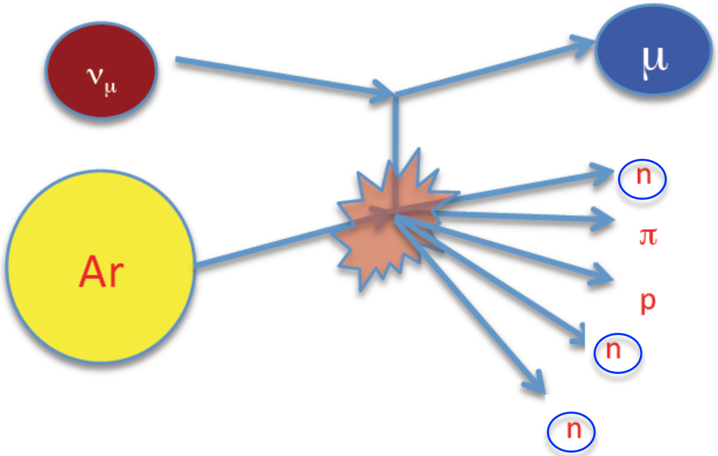
$$n + {}^{40}Ar \rightarrow n + {}^{40}Ar^*$$

- Measure cross sections of events that mimic the electron neutrino appearance signal in long-baseline neutrino physics.
  - The outgoing π^0 could be mis-reconstructed as an electron
  - Develop electron/photon separation technique



Neutron Run

- Undetected neutron in the neutrino interactions could lead poor reconstruction on initial neutrino energy.
- CAPTAIN will use neutron run to develop good understanding and methodologies to constrain the neutron energy in neutrino interaction.
- This will then be applied to the neutrino data collected at on-axis NuMI run.



Engineering run: Oct/Nov 2013
LArTPC data taking: Sep-Dec 2014

Signal detection

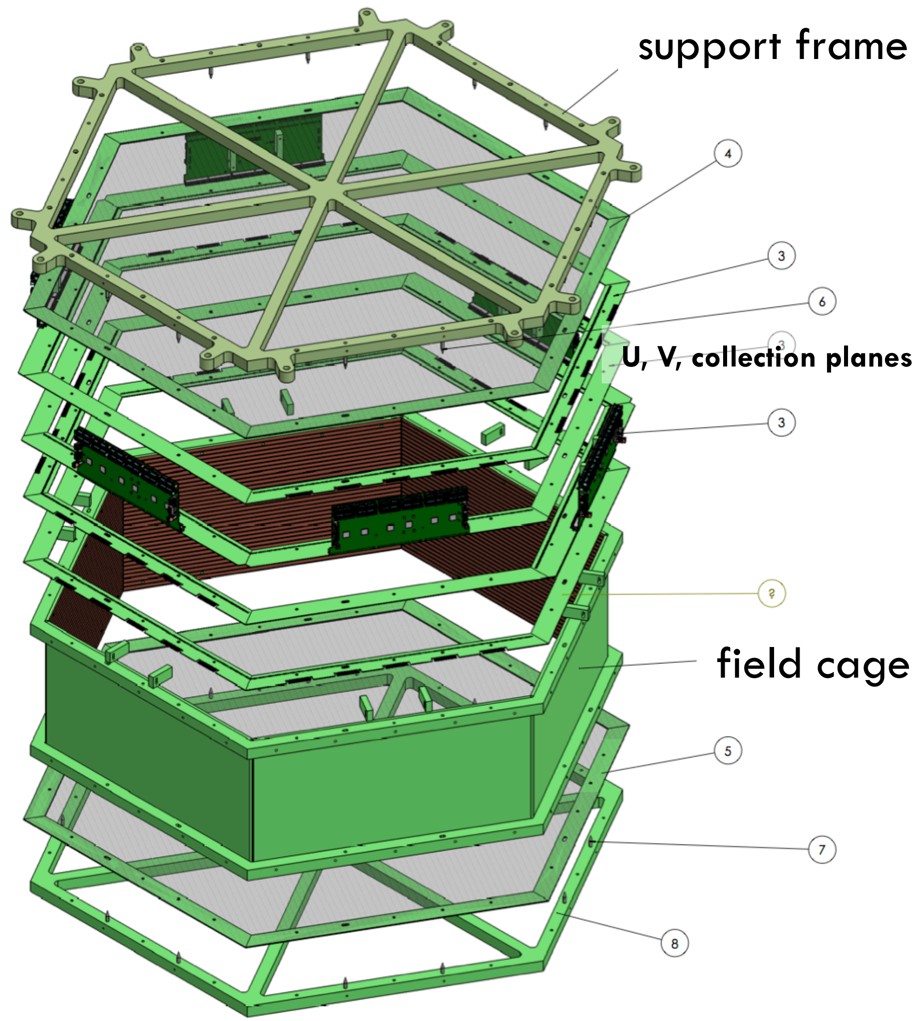
3 detection planes (U, V, collection)
667 wires each plane, 3 mm space
~2000 readout channels
75 μm diameter CuBe wire

Frames are made of FR4 glass fiber composite

1m maximum drift distance (vertical)

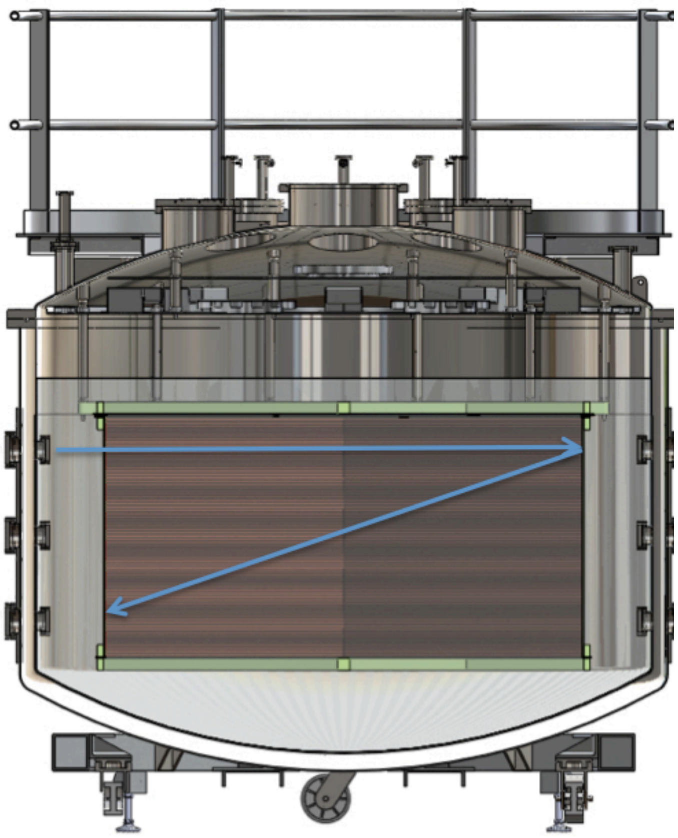
Electric field 500 V/cm
Drift velocity 1.6 mm/μs

Same electronics as MicroBooNE



Laser system

- Quantel "Brilliant B" Nd-YAG laser
  - 266nm (4.66 eV), 90 mJ
  - Liquid argon atom ionization energy is about 14 eV, need 3 photons to produce an electron
- Measure electron lifetime in situ
- Measure drift electric field in presence of cosmic (distortion of electric field is a challenge to LBNE surface far detector)
- Study liquid argon ionization and electron recombination (laser power, impurities, electric field)



B. Rossi, et al. 2009 JINST 4 P07011

We also have a mini-CAPTAIN

- A prototype cryostat (1700 L) from D. Cline and H. Wang(UCLA)
- A same shape and smaller size TPC
- Test purification system and establish operational plan
- Test run for data acquisition and event reconstructions
- Test for laser calibration
- Gain experience so we can focus more on physics measurements for the full-size CAPTAIN

Experiment Status

- Assembly has began in August 2013
- Commissioning and testing (laser and cosmic ray data analysis)
  - Mini-CAPTAIN late 2013
  - Full-size CAPTAIN, before summer 2014
- Physics Programs
  - Neutron run beam test Nov. 2013, liquid argon data taking after summer 2014
  - Supernova neutrino run Oak Ridge SNS, proposing beyond 2015
  - Medium energy neutrino run Fermilab NuMI on-axis, proposing beyond 2015
  - Muon data at TRIUMF in 2015?

Summary

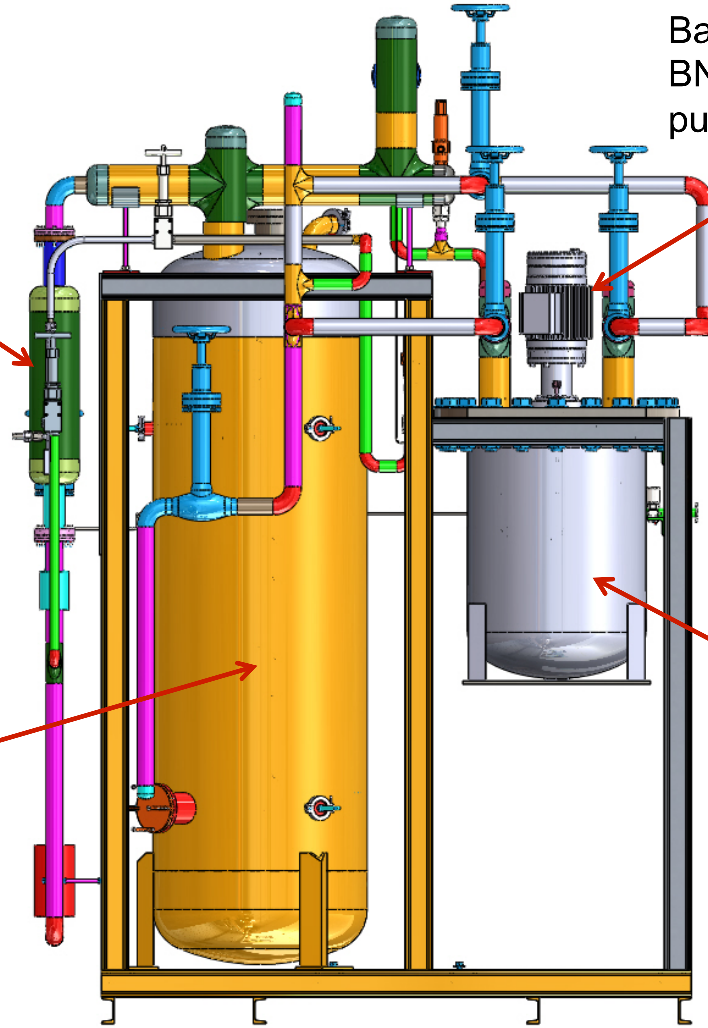
- CAPTAIN is a liquid argon TPC experiment
  - Detectors are available soon (mini-CAPTAIN late 2013, CAPTAIN early 2014)
  - The whole system is transportable
- The focus on physics and a variety of potential physics topics provides HEP community a great place to analyze data and train students
  - Neutron run
  - Medium energy neutrino
  - Supernova neutrino
  - Tens of thesis topics
- Numerous collaborating possibilities
- Real work now begins
- Contact: Christopher Mauger (cmauger@lanl.gov)

BACK UP

Purification system

Sintered metal filter used to remove dust, before Argon gets to cryovessel

Barber Nichols BNCO-32-000 liquid Argon pump

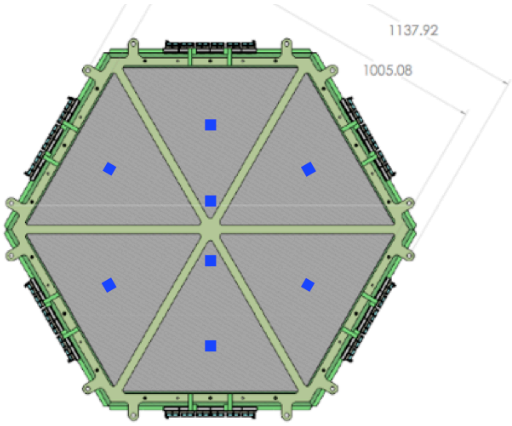


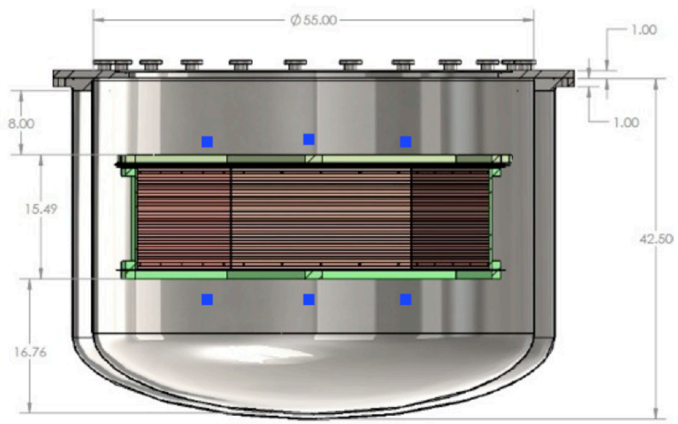
Liquid Argon filter vessel

Recirculation pump vacuum vessel

Photon detection

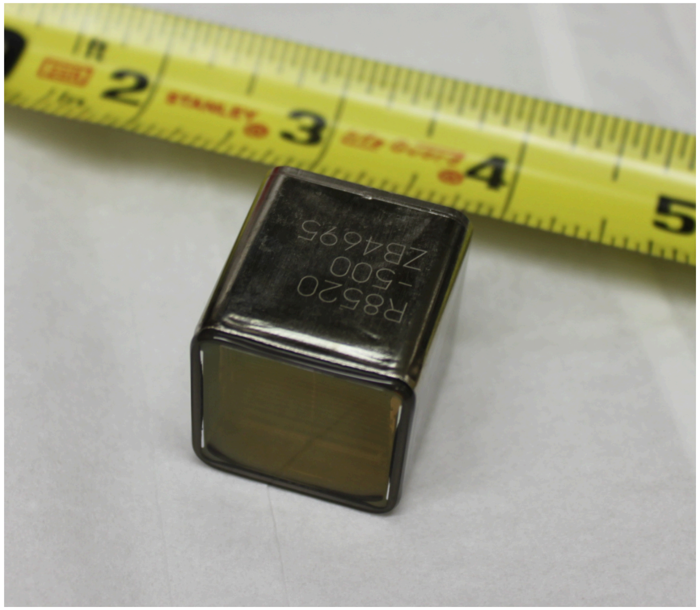
- 16 Hamamatsu R8520-500 PMT for light detection
- Photon detection could be used to trigger non-beam events and to improve the energy resolution
- Serves as TOF for neutron run
- CAPTAIN would also enable testing the other types of wavelength shifter and PMT for liquid argon detector

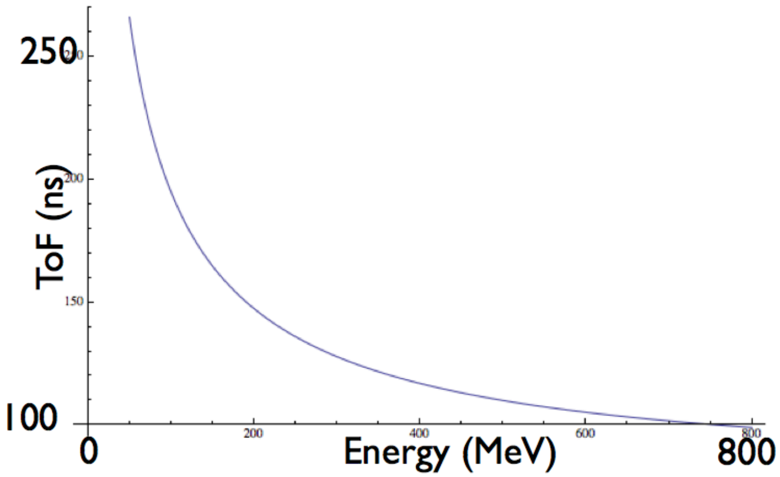




Photon Detection

- Liquid argon scintillation light 128 nm; need wavelength shifter to shift the light to be visible.
- Use tetraphenyl butadiene (TPB) as wavelength shifter
- 16 Hamamatsu R8520-500 PMT for light detection





Laser Calibration System

Quantel “Brilliant B” Nd-YAG laser

Wavelength	1064 nm	532 nm	266 nm
Pulse Energy	850 mJ	400 mJ	90 mJ
Pulse Duration	6 ns	4.3 ns	3 ns
Peak Power	133 MW	87 MW	28 MW
Peak Intensity	1500 GW/cm^2	985 GW/cm^2	317 GW/cm^2
Photon Energy	1.17 eV	2.33 eV	4.66 eV
Photon Flux	8E30 γ/(s·cm^2)	2.6E30 γ/(s·cm^2)	0.42E30 γ/(s·cm^2)

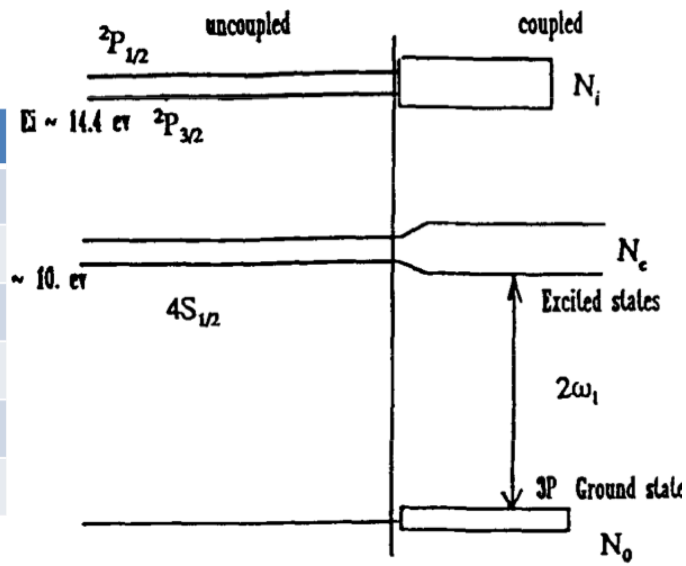
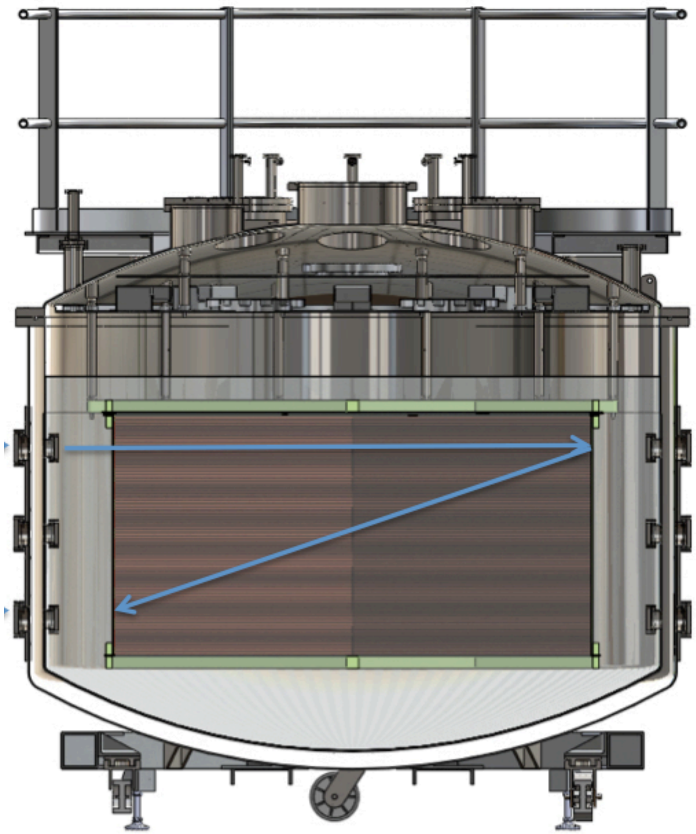
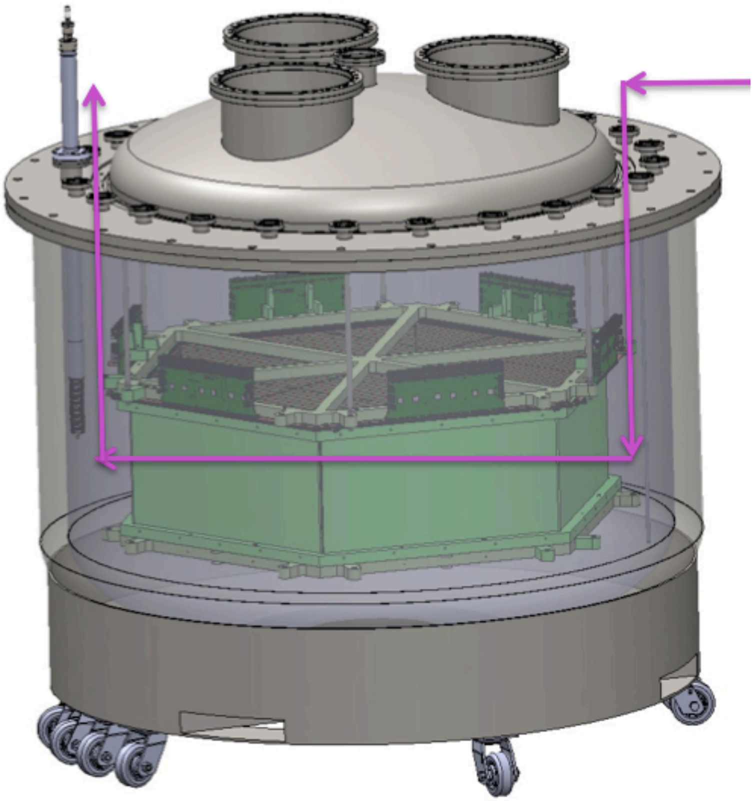


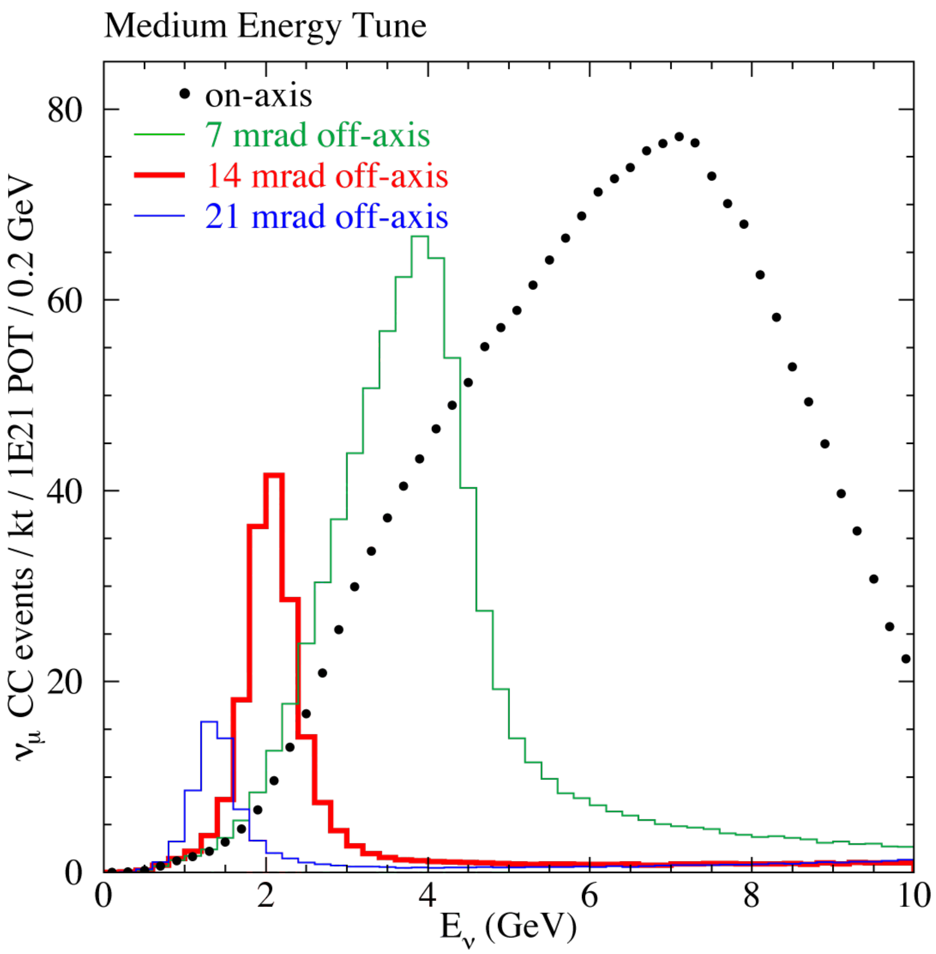
Fig. 5. Liquid argon atom energy level sketch.

Laser in CAPTAIN and mini-CAPTAIN

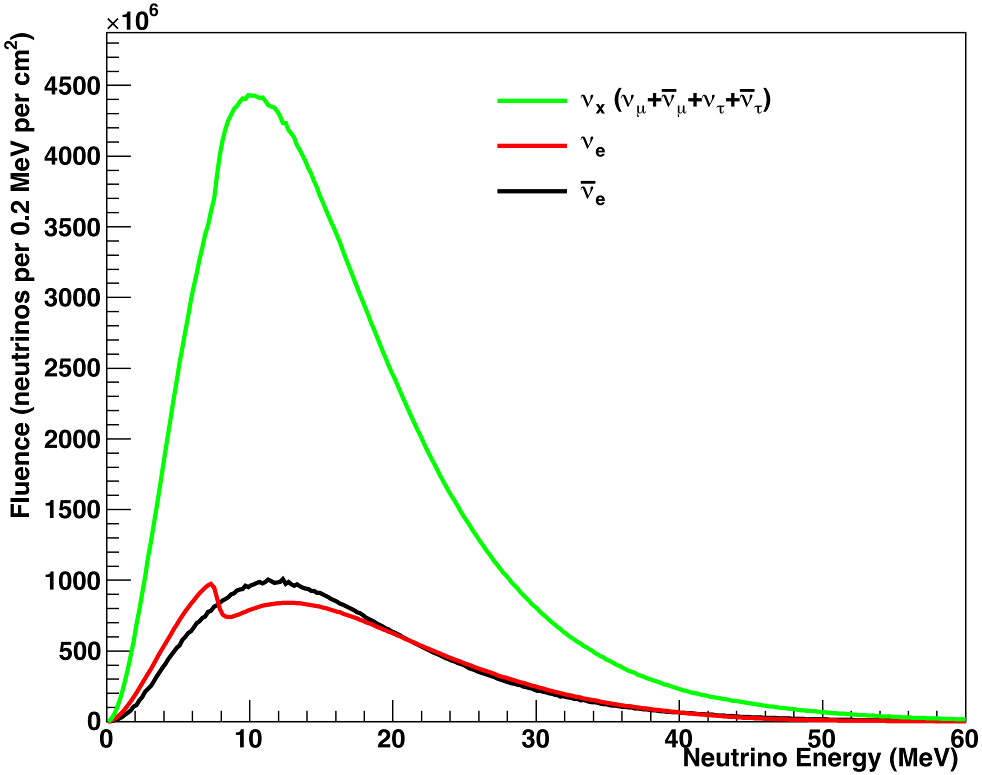




NuMI energy


Medium Energy Tune
on-axis
7 mrad off-axis
14 mrad off-axis
21 mrad off-axis
ν_μ CC events / kt / 1E21 POT / 0.2 GeV
0
20
40
60
80
0
2
4
6
8
10
E_ν (GeV)

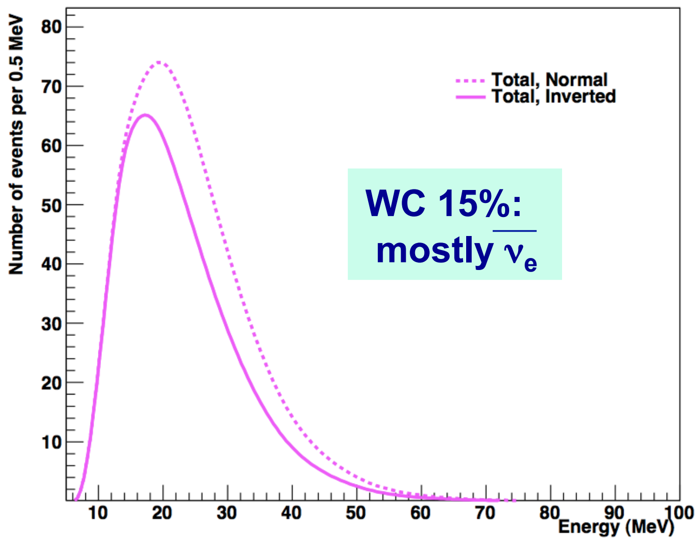
Supernova neutrino

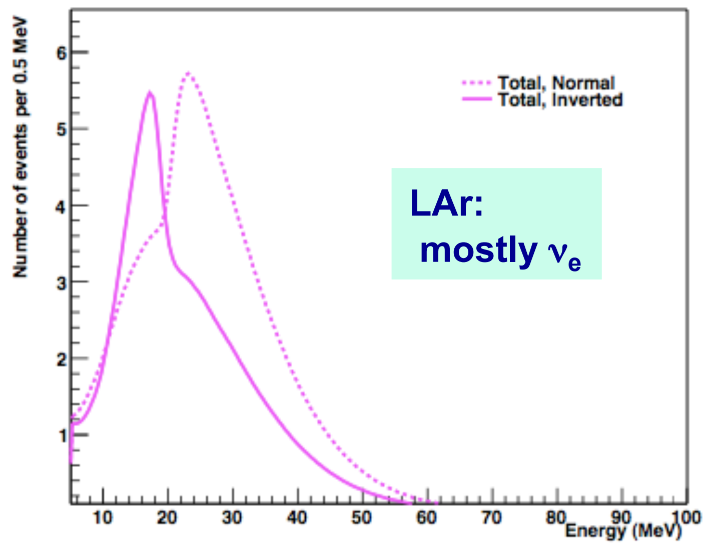


Observability of oscillation features: example

Can we tell the difference between normal and inverted mass hierarchies?

(1 second late time slice, flux from H. Duan w/collective effects)





Differences, but no sharp features

LAr shows dramatic difference

`Anecdotal' evidence is good... systematic surveys underway